Focus on Partnering

QWIP QDIP & SLS for Infrared Detection

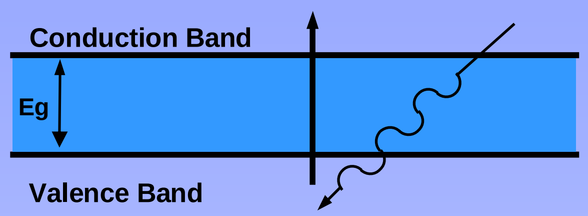
Briefing for Industry

OUTLINE

- Introduction to IR detection based on quantum structures
- Quantum well for IR detectors
- Quantum dot for IR detectors
- Strained Layer Superlattices for IR detection
- Summary

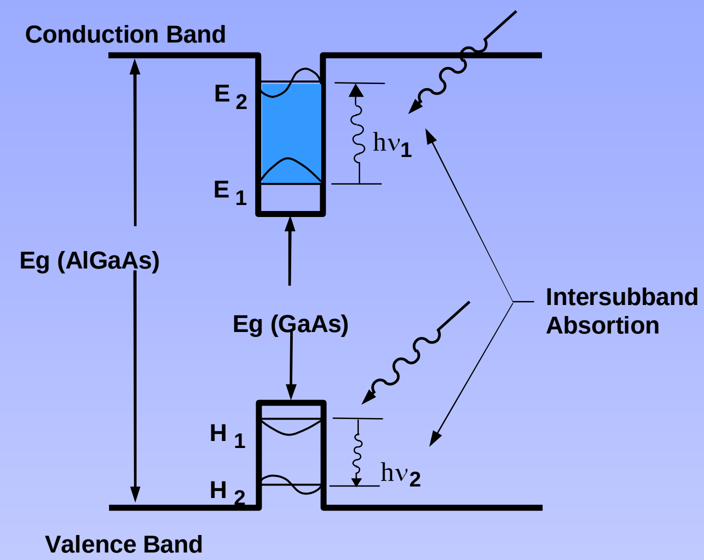
Infrared Detector Structures

Conventional Intrinsic Infrared Photodetector



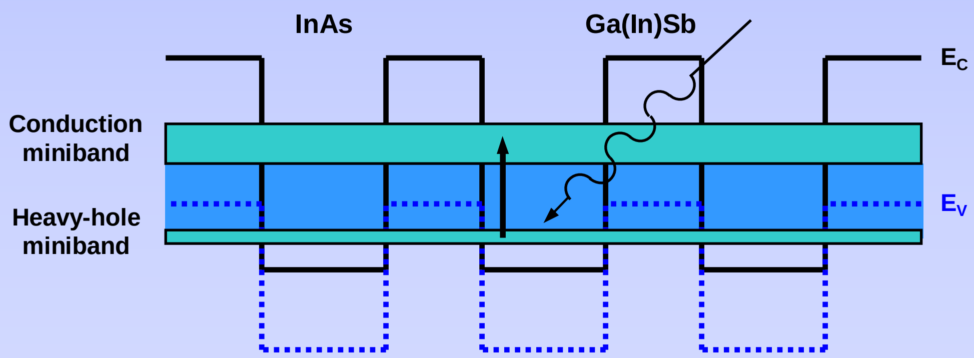
- High quantum efficiency
- Established industrial knowledge base
- No large area lattice matched substrates
- Can be difficult to grow & process (uniformity)
- Possibility of mid-gap metastable traps

Quantum Well Photodetector



- Large lattice matched substrates up to 8-inch
- Highly mature materials & processing technology
- High pixel uniformity & operability
- No unstable mid-gap traps, radiation hard
- No normal incidence absorption

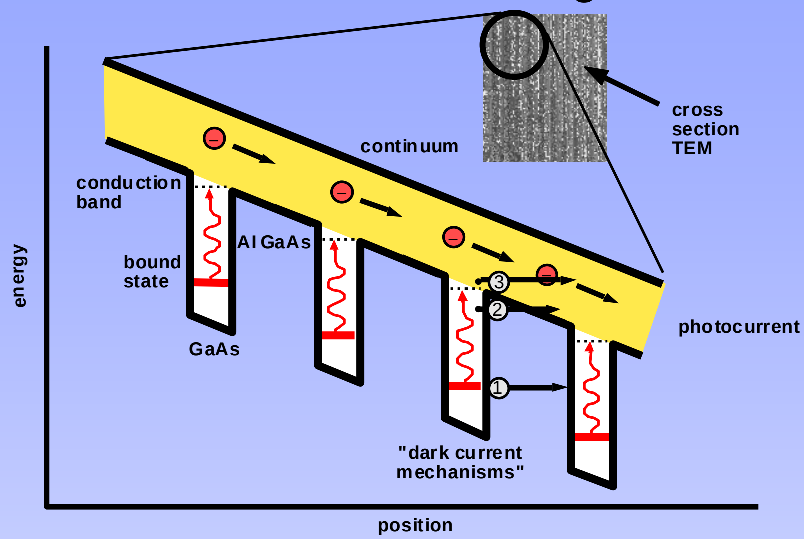
Schematic Band Diagram of a Superlattice

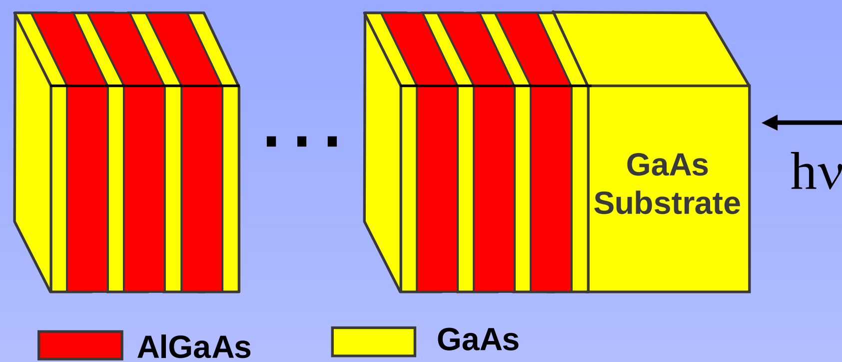


- High quantum efficiency
- High operating temperature
- Take advantage of III-V materials processing technology
- Tunable in a very wide range of wavelengths
- High quality 4” GaSb substrates are coming out now

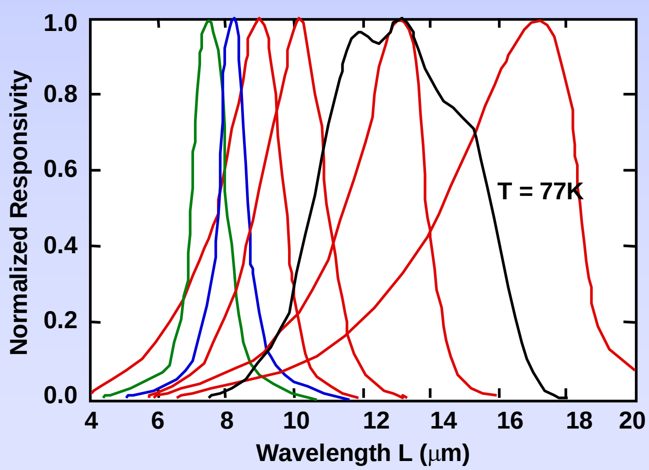
Quantum Well Infrared Photodetector (QWIP) Focal Plane Array Technology

Conduction Band Diagram





GaAs/AlGaAs Based QWIP Spectrums

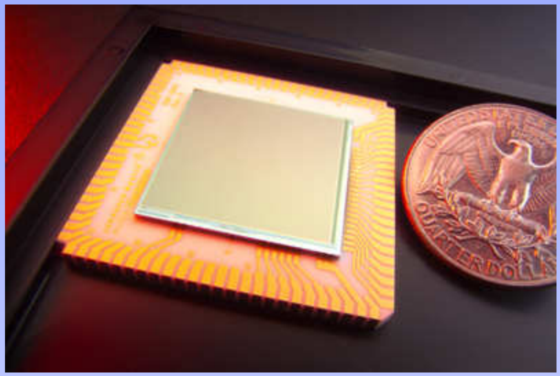


GaAs/AlGaAs Based QWIP Can Cover a Very Broad Infrared (3-25 μm) Region

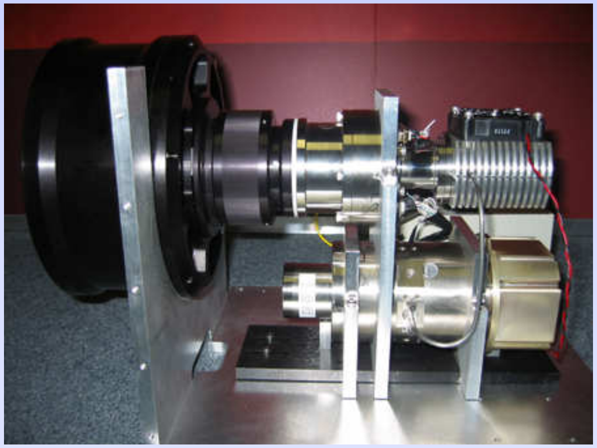
Veeco 4-inch capable GEN-III Molecular Beam Epitaxy Growth Machine

1024 x 1024 PIXEL QWIP

1024 x 1024 QWIP Focal Plane Array



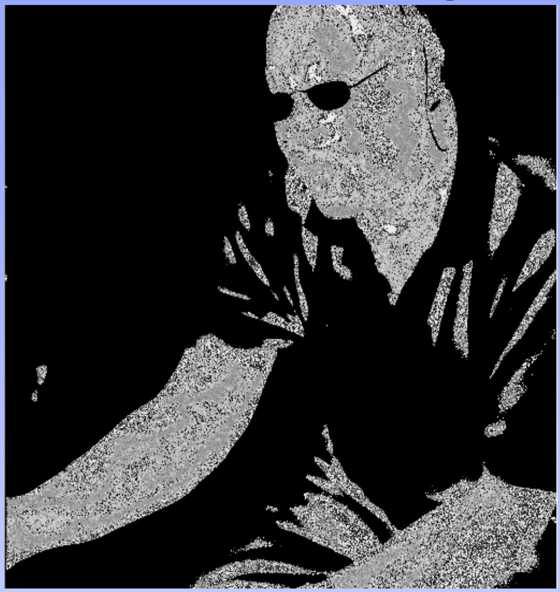
Portable Camera

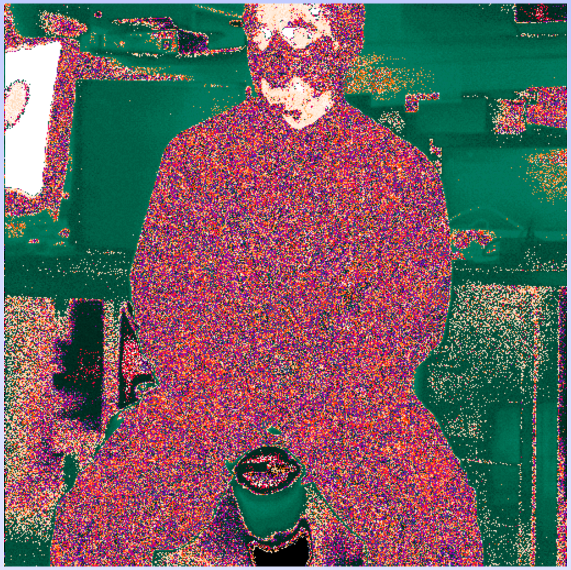


Advantages

- High yield
- Large formats FPAS
- Tailorable-wavelength
- Broad-band, dual-band, and
  narrow-band
- No delamination effects
- Low 1/f noise
- High uniformity
- High operability
- Radiation hard
- Availability

Imagery





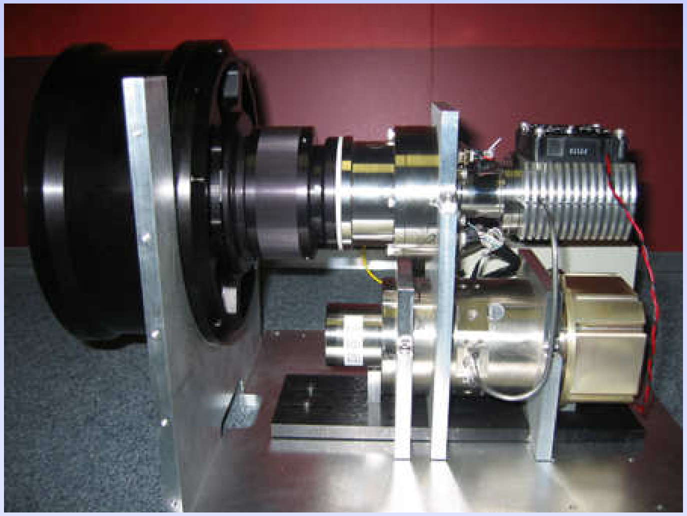
- NEΔT OF 13 mK was achieved.

QWIP Cameras

Palm-size with 256x256 FPA

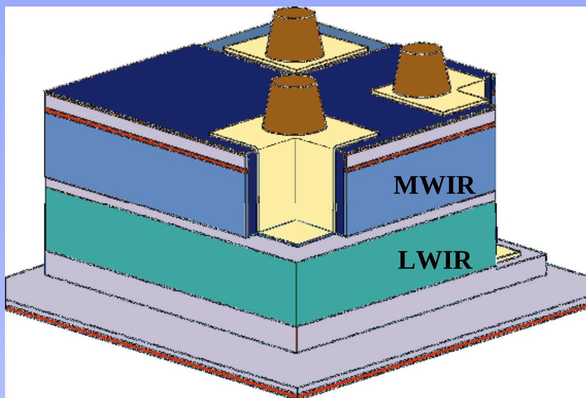
Hand-held with 320x256 FPA

Hand-held with 640x512 FPA

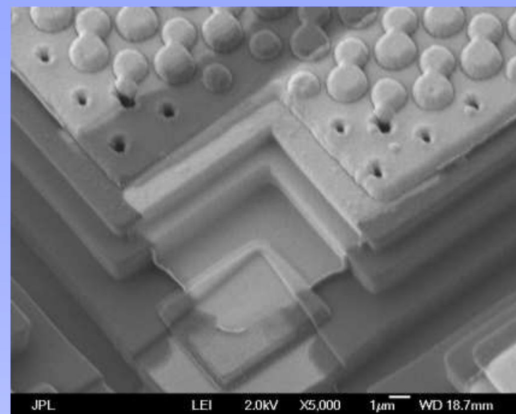


Desk-top with 640x512 dual-broadband FPA

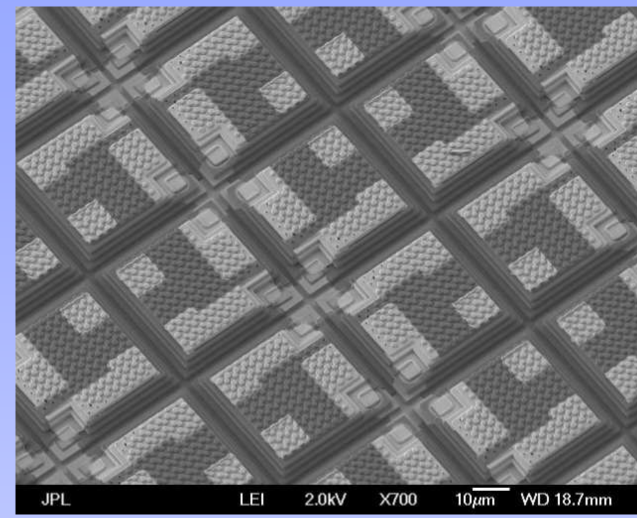
PIXEL CO-LOCATED SIMULTANEOUSLY READABLE DUALBAND QWIP FPA



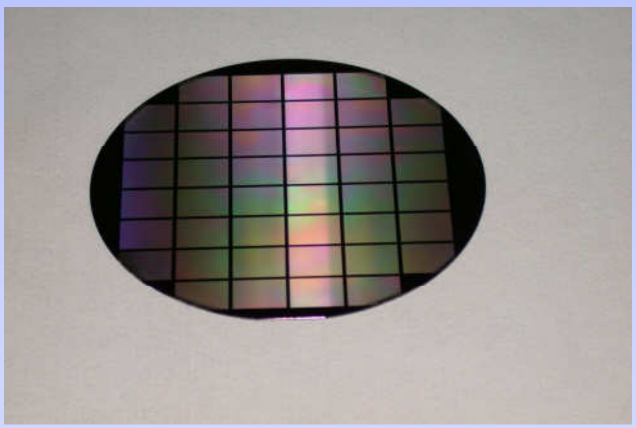
Dualband QWIP device structure



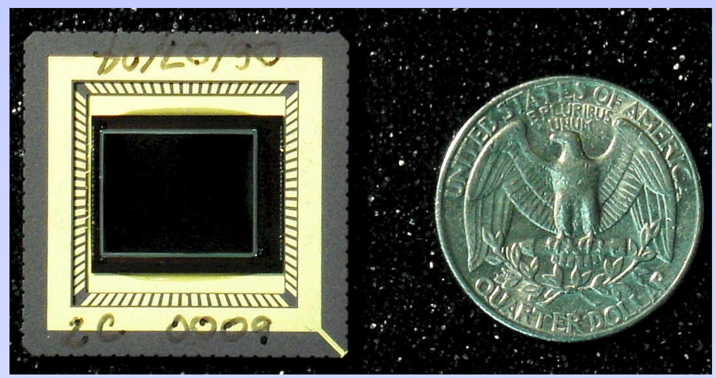
SEM of metal via connects



SEM of dualband QWIP array

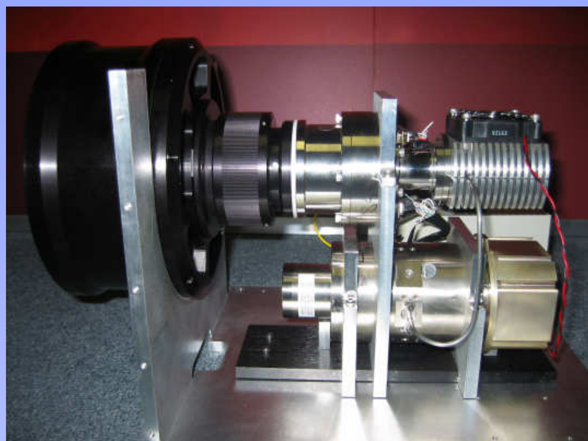


4-inch wafer with 48 detector dies



Dualband QWIP FPA HYBRID

DUALBAND QWIP CAMERA & IMAGERY



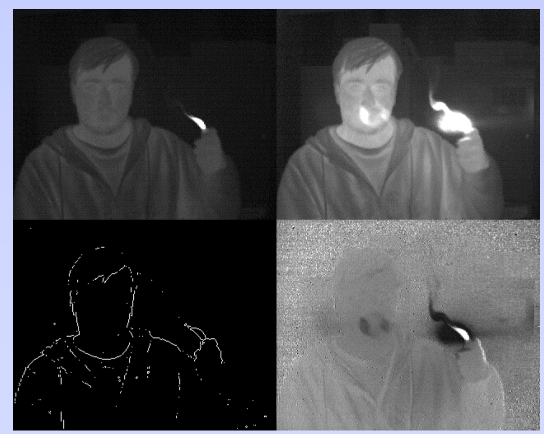
Dualband sensor engine

LWIR **MWIR**

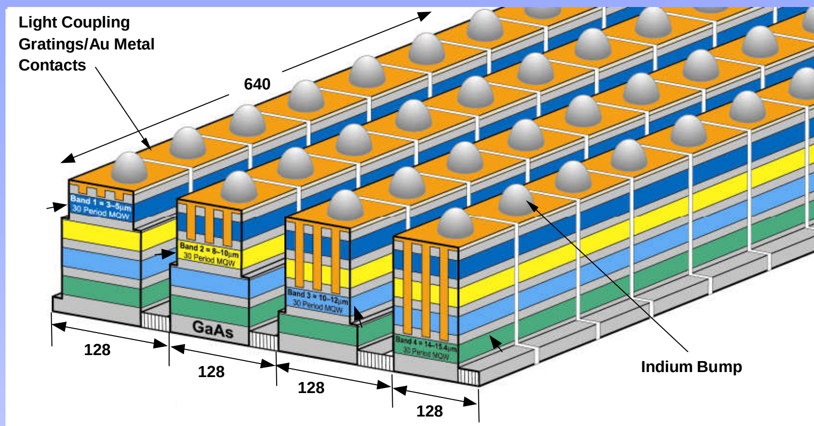
Features to look for,

The cigarette lighter produce lots of hot CO_2 gas. So, flare is broader MWIR due to CO_2 emission, where as LWIR (8-9 microns) doesn't have any emission (just the heat).
The hot cigarette lighter flame produce so much MWIR signal, it reflects off from the lens and Jason's face.
The plastic piece Jason is holding is opaque in LWIR, but transparent in MWIR.

Format	- 320x256 pixels, dualband & pixel co-registered
Wavebands	- 4.4-5.1 & 8-9 μm
NEDT	- 22 & 24 mK for 300K background with f/2 optics
QE	- 19% & 15%
Photoconductive gain	- 0.2 & 0.3
Detectivity	- > 2×10^{11} & 1×10^{11}Jones
Operating temp.	- 65 K
Fill factor	- > 81%

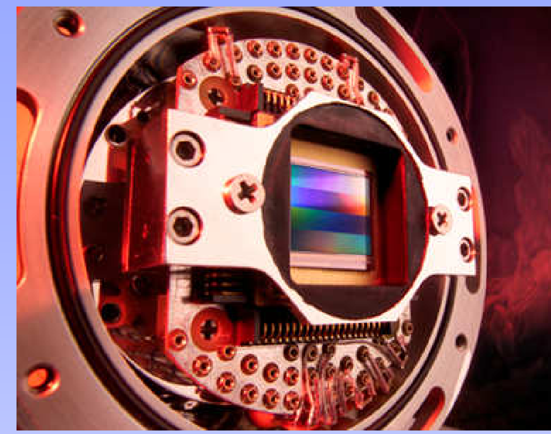


Four-band Focal Plane Arrays

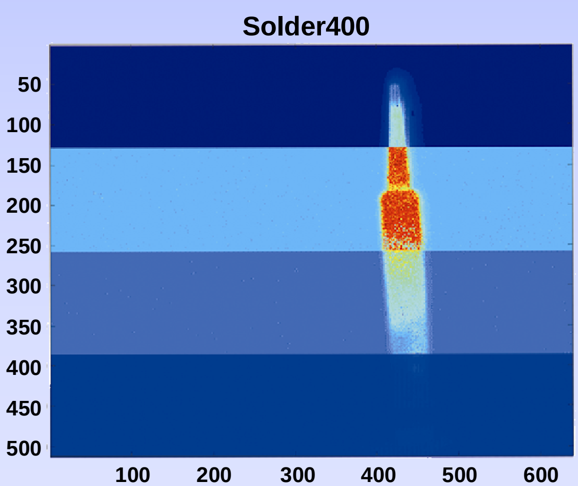


Four-band QWIP Device

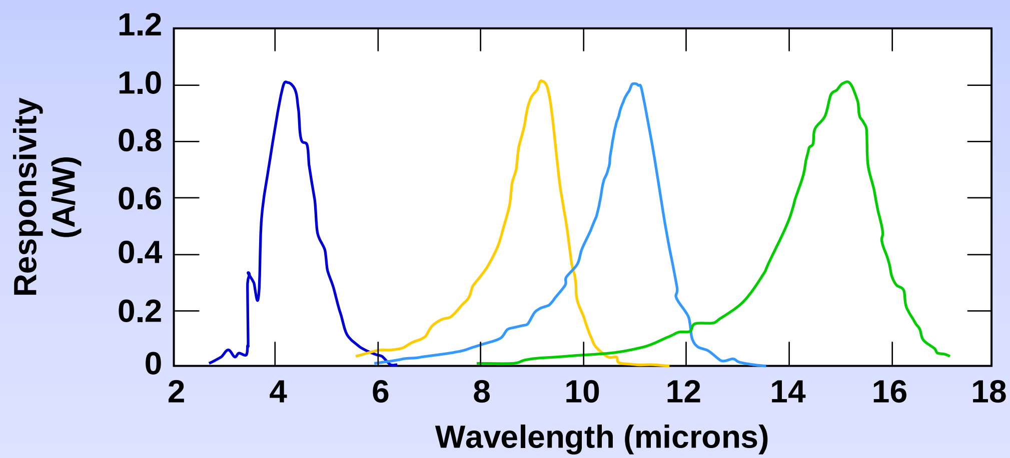
Four-band FPA



Four-band FPA in Dewar



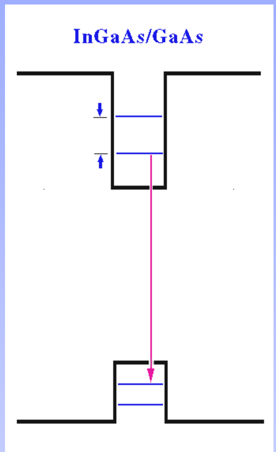
Four-band Imagery

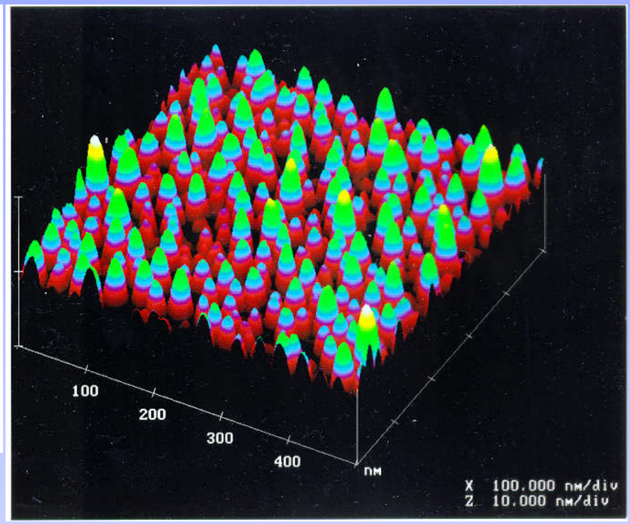


Four-band Spectral Response

Quantum Dots for IR Detection

Quantum dots are very small semiconductor structures (nanometers or tens of nanometers in diameter) surrounded by a material of a wider bandgap. They confine electrons and holes in three spatial dimensions and to a very small number of energy levels, depending on their size. They respond very efficiently to particular wavelengths of light.



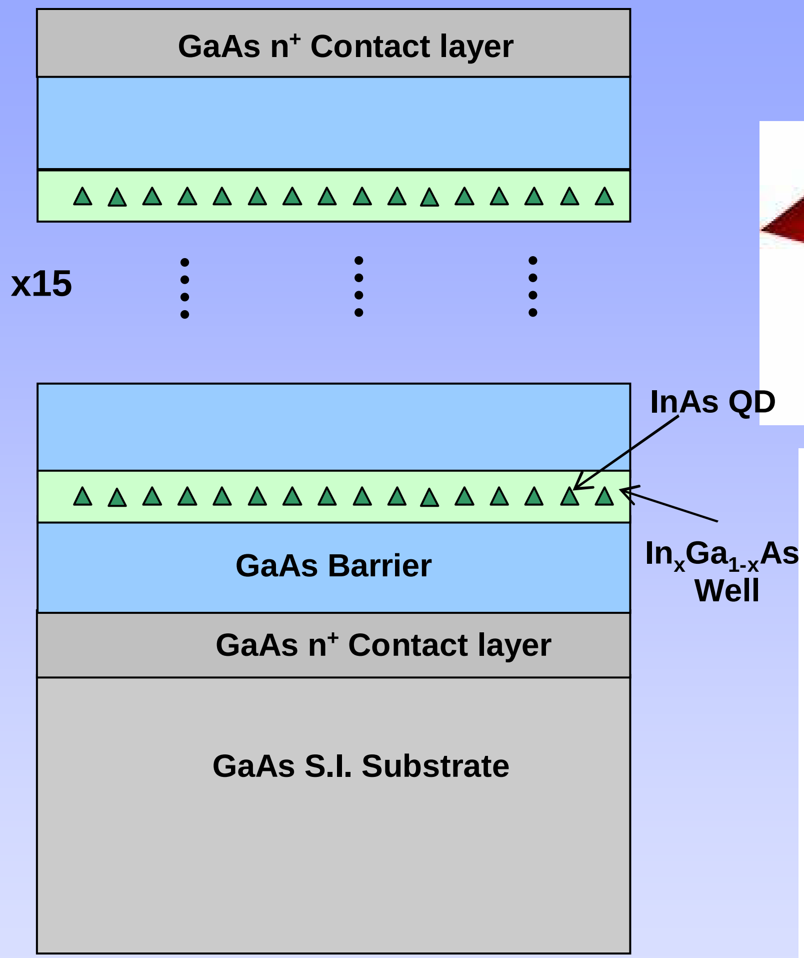


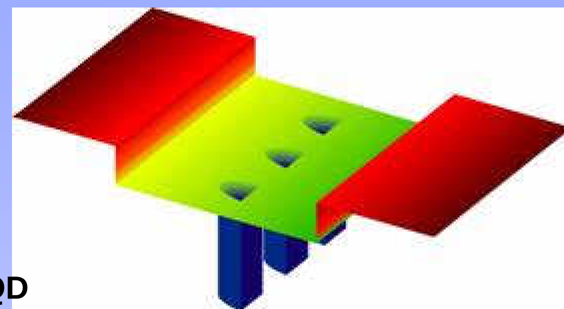
Quantum dots (QDs): structures capable of confining carriers in three dimensions

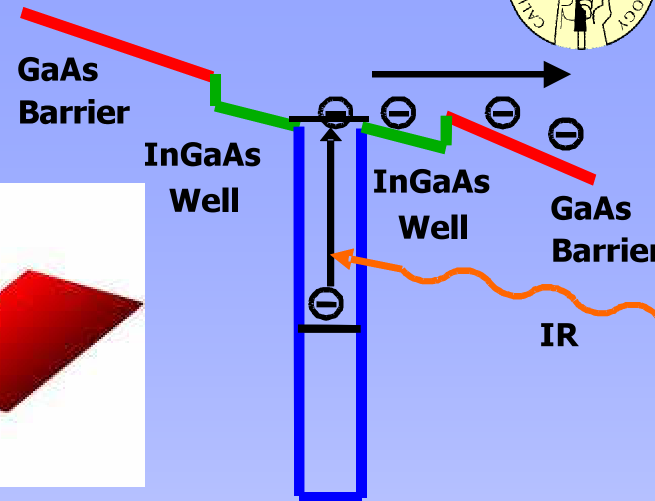
3D quantum confinement → enables normal incidence → quantum efficiency

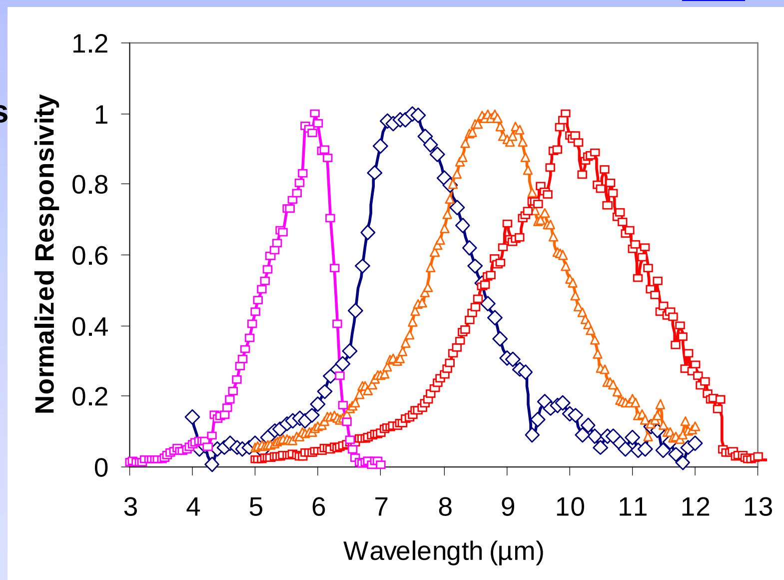
Phonon bottleneck → increase carrier lifetime → raises operating temperature

Dot-in-a-Well (DWELL) QDIP









Experimental measurements show continuous tunability via well width variation

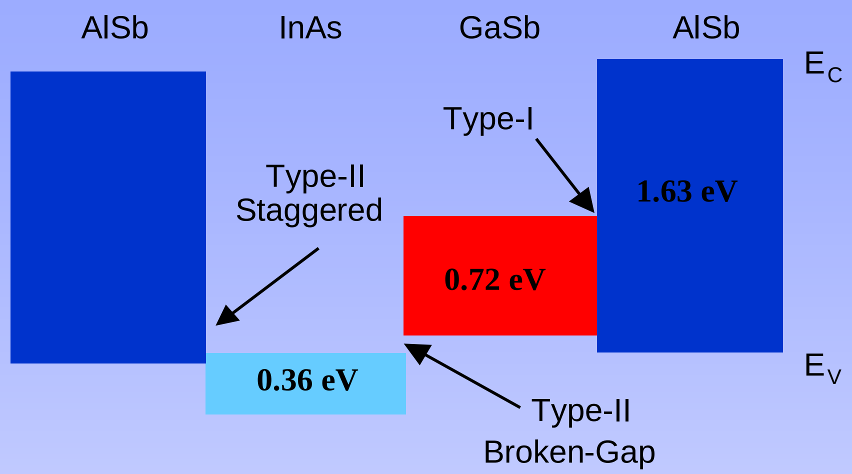
- Embed InAs dots in InGaAs quantum wells
- Motivation: Precise control of quantum well width allows easy wavelength tuning

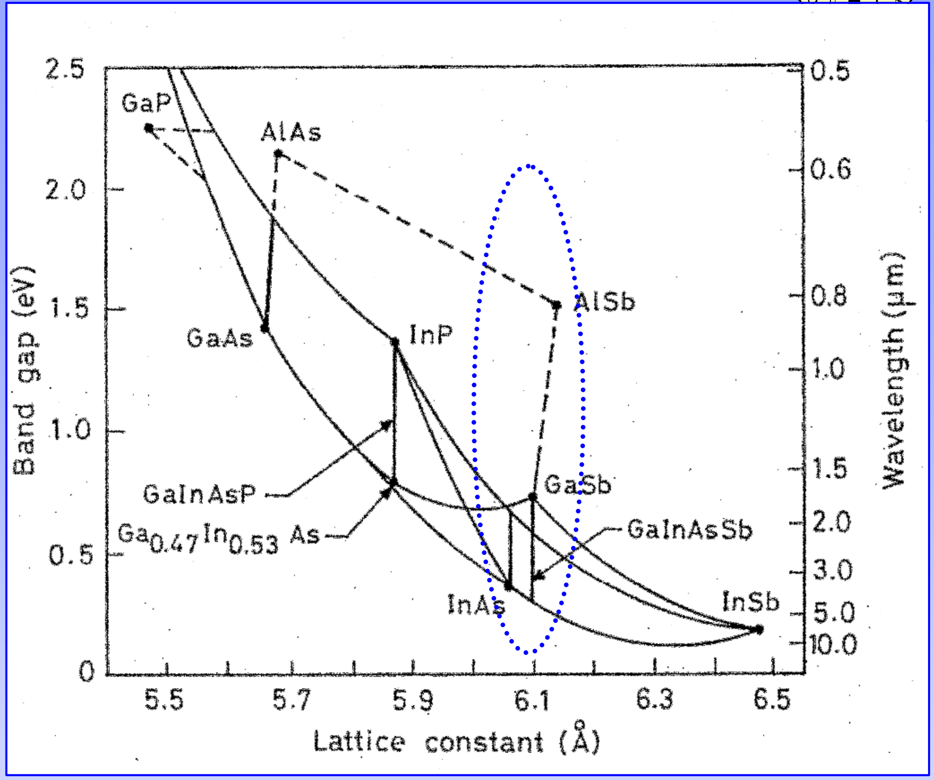
LWIR Imaging with QDIP FPA

- First 640x512 QDIP imagery taken at 60 K using f/2 optics
- Non-uniformity <0.2% (corrected); operability >99.9%; NEDT = 40 mK

- First 1024x1024 imagery taken at 80 K using f/2 optics
- Absorption Quantum efficiency – 20%, Non-uniformity <0.1% (corrected); operability >99.8%; NEDT - 31 mK

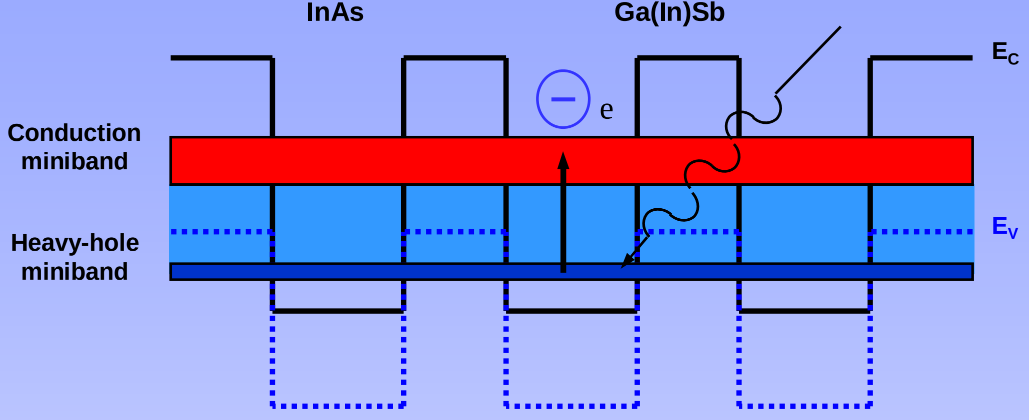
Strain Layer Superlattice for IR Detection

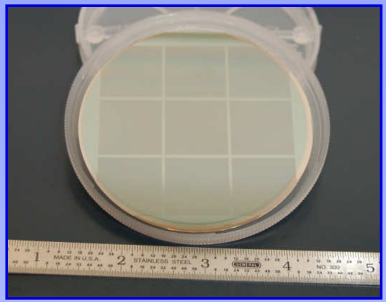




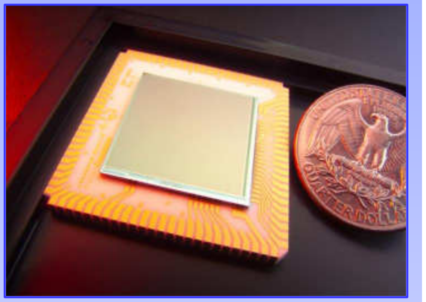
- **Superlattice: repeating crystalline superstructure**
  - **For device physics we add that the periodicity is such that quantum mechanical interactions take place between neighboring periods (c.f. QWIPs)**
- **For these devices, we deposit alternating layers of InAs and Ga(In)Sb with atomic layer precision using molecular beam epitaxy (MBE)**
  - **Compensate net strain with alloying or interface engineering**
- **Form a p-i-n detector structure by doping the superlattice layers with trace amounts of Be(p), Te(n), or Si (both)**
- **Conceptually simple process**
  - **Requires complicated capital equipment like MBE**

Advantages of Superlattice Detectors





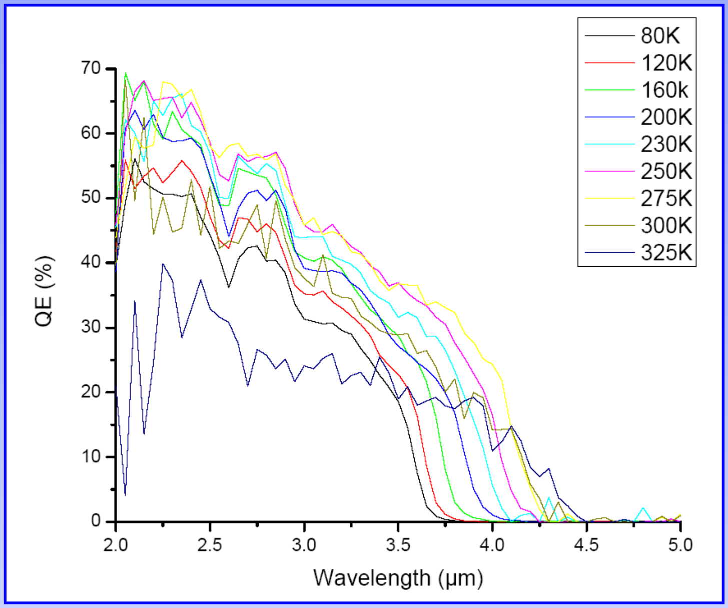
Five megapixel arrays on 3”GaSb wafer

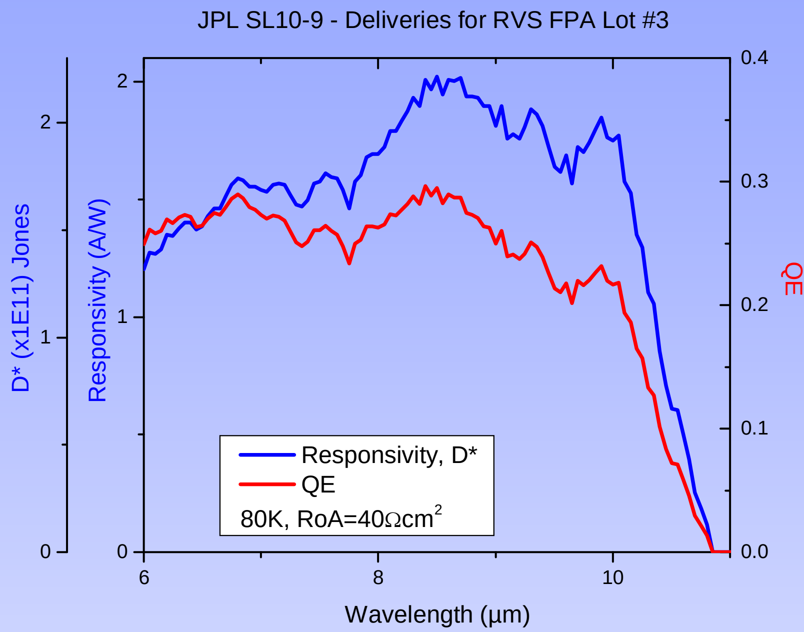


megapixel array on LCC

Superlattice Characteristic	Advantage	Tangible Benefit to FPAs
Band structure engineering	Suppress Auger related dark current	Higher operating temperature
Large electron effective mass	Smaller leakage currents	Higher detectivity
Interband transitions	Normal incidence absorption	High quantum efficiency (fast arrays)
Adjustable bandgap	Tunable cutoff from 3 to 20µm	Multicolor capability
III-V semiconductor based	Highly uniform	Cheap, robust, uniform

MWIR & LWIR Photodiodes



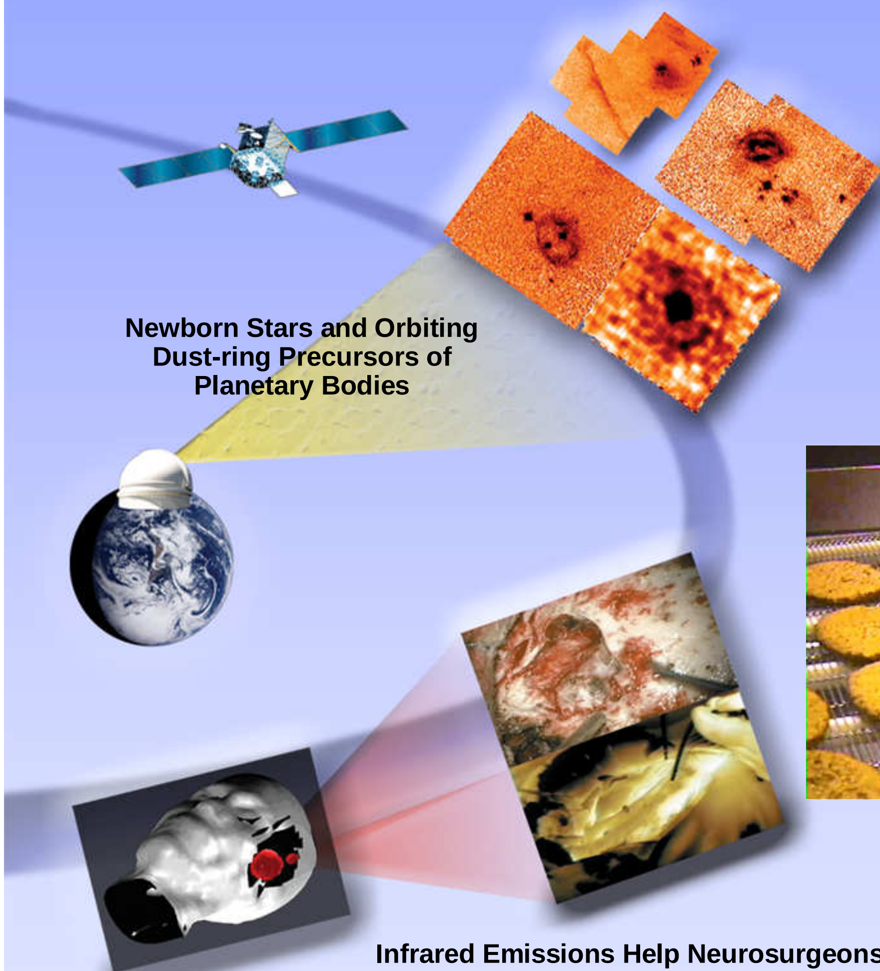


- We are developing SLS based MWIR & LWIR detectors for FPA applications
- ~3.7 microns cutoff, D*~1x10E11D* imaging arrays at ~200K for a 3.7µm cutoff
- ~10 micron cutoff, D* ~ 2x10E11 Jones at 80K
- ~12 micron cutoff, D* ~ 8x10E10 Jones at 80K

First megapixel SLS images

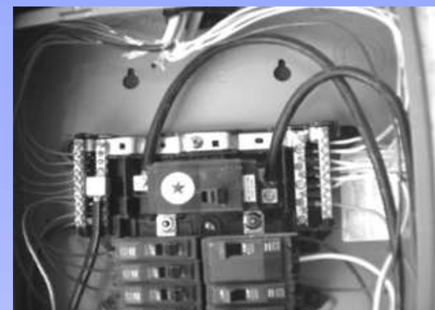
- DPT thinned pathfinder array imaging at 80K, demonstrating large area capability
- Our first batch has some problems on the edges
- Still optimizing for good passivation compatibility with the ROIC

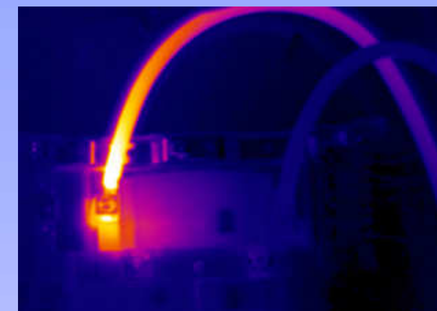
QWIP Camera Applications and Commercialization

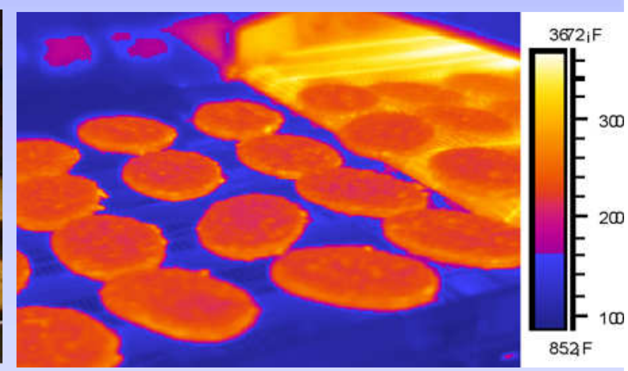


Newborn Stars and Orbiting Dust-ring Precursors of Planetary Bodies

Infrared Emissions Help Neurosurgeons Better Visualize Tumors Before They Operate and Also Find Tiny Clusters of Cancerous Cells that Might Remain after Surgery.

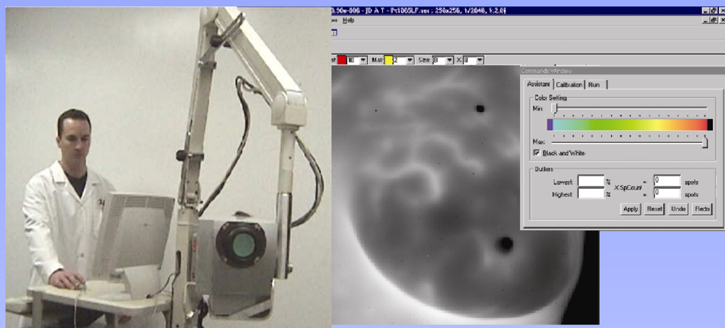




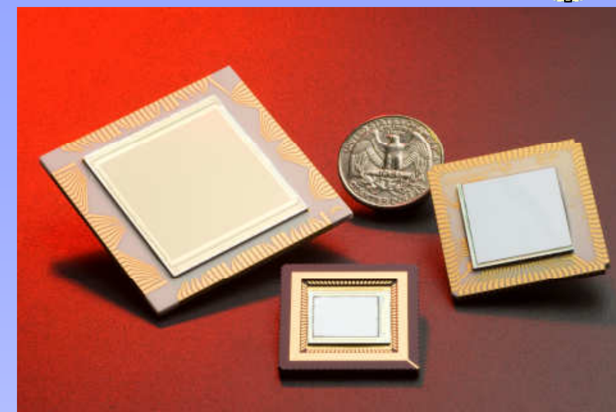


- JPL holds seventeen QWIP patents. Two small industries.

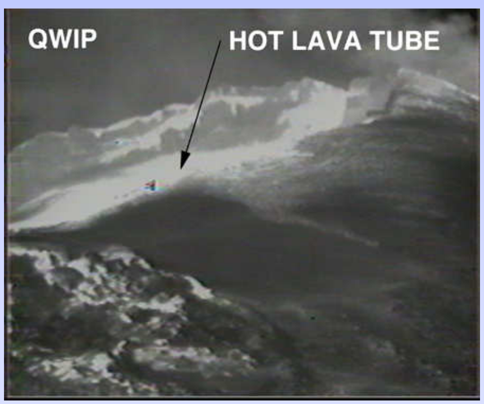
QWIP Camera Applications and Commercialization



FDA-approved Techniques for the Early Detection of Breast Tumors



Size comparison of current QWIP FPAs at JPL



Underground Flow in a Lava Tube at the Kilauea Volcano

JPL Parking Lot Through an Entire Day

Lingering Hotspots of the 1996 Malibu Fires Imaged Through Smoke

- Thermal Imaging QWIP Cameras have been used in Myriad Applications such as the Early Detection of Tumors, Fire Fighting, Advanced Missile Detection and Tracking, and Astronomy.

Partnering & Commercialization

- Industrial partners
  - Lockheed Martin
  - Raytheon
  - Boeing
  - FLIR
  - IQE
  - QmagiQ, LLC
  - BAE
- Commercialization
  - 17 patents & over 200 publications
  - QWIP Technologies, LLC
  - OmniCorder Technologies, LLC